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REPORT OF INVESTIGATIONS/1993

Innovative Method for Casting Steel Armorplate

By Paul C. Turner and Jeffrey S. Hansen

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	m	meter
cm	centimeter	mm	millimeter
kg	kilogram		

INNOVATIVE METHOD FOR CASTING STEEL ARMORPLATE

By Paul C. Turner[1] and Jeffrey S. Hansen[2]

ABSTRACT

The U.S. Bureau of Mines, through an Interagency Agreement with the U.S. Army Tank-Automotive Command (TACOM), has successfully developed a steel expendable pattern casting process (EPC) for the manufacture of armorplate. The new armor is lighter and more ballistically effective than conventional rolled homogeneous armor (RHA), and costs less. An applique armor spinoff from the program was field-tested during the Gulf War. The applique armor withstood direct impacts from enemy munitions without failure.

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INTRODUCTION

As part of an Interagency Agreement with the U.S. Army Tank-Automotive Command (TACOM), the U.S. Bureau of Mines Albany, OR, Research Center successfully developed an innovative modification of the expendable pattern casting process (EPC) and produced a number of complex castings for a Bradley Fighting Vehicle commander's hatch program. The work was performed in conjunction with Lanxide Armor Products of Newark, DE.

The focus of the program was to replace the current aluminum commander's hatch, shown in figure 1, with a composite hatch composed of an outer covering of perforated steel, a middle layer of a proprietary Lanxide ceramic composite, and an inside layer of steel. The perforated design contained multiple, angled slots and was designated by the Army as P-900. The design of the P-900 outer layer served two purposes: to break up incoming projectiles and to lock in the ceramic layer. The Army originally perceived the outer hatch as a multicomponent weldment, but after discussions with the Bureau, the Army decided to make the hatch as a one-piece casting.

The Bureau's task in this project was to produce the P-900 outer hatch covers. Lanxide's task was to provide the ceramic investment. The P-900 slot configuration presented a complex manufacturing problem. The multiple, angled slots could not be fabricated easily by punching rolled plate on a press, and conventional methods of casting were not adaptable to the slot arrangement. Investment casting and machining were both conceivable, but far too expensive.

EXPENDABLE PATTERN CASTING PROCESS

The EPC process was selected to make the armor because it was ideally suited for the slot configuration and because its economies were documented in the casting of aluminum (*1-3*).[3] The process had not been used previously to manufacture steel castings.

In the EPC process, molten metal is poured directly into a polystyrene pattern that is embedded in unbonded sand. The pattern vaporizes, and the metal assumes the pattern's configuration (*4*). While most problems in casting aluminum using the EPC process have been resolved, the techniques for aluminum EPC are not readily transferable to steel EPC, which entails additional problems. The replacement of a pattern by molten aluminum during pouring proceeds slowly, and the pattern and aluminum are in constant contact (*5*). With steel, the pattern tends to evaporate as soon as hot metal enters the mold (*6*). Therefore, molds may collapse well before metal is available to replace the pattern. Also, steel castings tend to be larger than aluminum castings, and therefore, the patterns are less rigid. Pattern handling is more difficult, especially if parts have thin walls or rangy sections. Unique casting defects are likely if pattern byproducts are not eliminated before the liquid steel takes its place.

The P-900 hatch cover was cast successfully by modifying the EPC process for aluminum casting and adapting it to steel. Three innovations were added to the aluminum EPC process to make the successful adaptation for steel: (1) double-walled sand flasks were developed for the application of vacuum to sand molds, (2) continuous narrow-necked feeding systems were used to deliver metal to all casting sections and to permit the casting of thin walls, and (3) bonded-sand cores were designed to hold critical hatch tolerances and allow features to be cast on the inside of the hatch.

STEPS IN HATCH CONSTRUCTION

EPC patterns are constructed by expanding polystyrene beads with pentane (no chlorinated fluorocarbons) (*7*). Commercially, patterns are made to the required size, but for development purposes in this study, patterns were made from a common preform containing the slotted configuration. The procedure for making the outer hatch started with manufacture of a chemically bonded-sand core that conformed to the inside dimensions of the hatch. The core assured rigid dimensional tolerances that were a design requirement of the hatch and allowed for features such as internal ribs used for supporting attachments on the inner portion of the casting. The core with rib impressions is shown in figure 2.

The polystyrene pattern for the casting was built over the core by gluing pattern sections to the core. Initially, when conventional bottom gating methods and standard runners and gates were used, metal failed to flow to all sections of the slotted armor hatch. Even with feeding assisted by vacuum, complete filling was achieved only

[3]Italic numbers in parentheses refer to items in the list of references at the end of this report.

after feeding distances were shortened to 8 to 10 cm by gating directly into the outside surfaces of the hatch. A primary runner was extended along the length of the casting at the bottom, and square, secondary runners were constructed to span the entire height of the hatch at intervals of 15 to 25 cm along the circumference. The runners were connected to the webs between the slots by gates. Delivery of hot metal through the relatively large secondaries to the much narrower webs of the plate helped ensure complete filling of castings and prevented premature mold collapse. When solidified, the runners and gates were removed easily with a hammer, requiring little finishing. A finished pattern is depicted in figure 3.

The pattern and core were sprayed with a refractory slurry of fine alumina-silica and binder. The refractory coating is necessary to keep intact the cavity that resulted after the pattern evaporated during pouring, and also to provide a better surface finish. The slurry was dried before molding the pattern in a vacuum flask. The flask was filled with unbonded silica sand and vibrated for compaction. The core fixture prevented distortion of the pattern by sand currents.

At normal casting temperatures, molten steel would not flow through the long, narrow slot webs and passages of the P-900 against the resistance of the pattern and pattern gases within the mold. With no means to enhance the flow, the results were frequent misruns. Application of vacuum to the mold provided the necessary flow enhancement and ensured complete filling. The vacuum aided metal feeding by effectively increasing the pouring height equivalent to about 1.5 m. In addition, the vacuum collected gases for disposal, added rigidity to the mold, and prevented cavity collapse.

Double-walled, steel molding flasks were used for vacuum application to the sand mold. A view of the flask with the coated pattern can be seen in figure 4. The inner walls consisted of fine mesh screens that were glued to perforated metal and bolted to appropriately spaced ribs in the flask. The screens confined the mold and prevented molding sand from entering the vacuum system. The flask was closed following pattern insertion, sand molding, and sand compaction by covering the top of the mold with a sheet of polyethylene film. Large-diameter hoses connected the flask with a vacuum system including a large surge tank. Vacuum was applied prior to pouring and discontinued after pouring. A sand pouring basin was placed on the top of the polyethylene film with its opening over the sprue.

After being poured, the casting was allowed to solidify and cool before removal from the flask. The sand core was separated from the unbonded sand. The sand required no treatment other than cooling before recycle.

Casting surfaces were relatively clean, in comparison with castings made with other processes, due to the absence of sand binder and binder-related defects. The gates were detached by impact with a hammer. Portions of gating that remained on the casting, although nearly insignificant, were removed by grinding. Figure 5 shows a rough casting just after removal from the flask.

The P-900 outer hatch, shown in figure 6, serves to illustrate the complexity and detail possible with the process. The dimensions of the final casting are 70 cm by 56 cm by 25 cm high, with a weight of about 23 kg. Tolerances were kept within 1.5 mm over the length of the casting. Outer and inner surfaces of the casting had excellent surface finish and demonstrated the ease with which features can be cast on the inner surface of the casting. Even the bead structure of the polystyrene pattern was reproduced in the casting and is evident in many of the oblong slots shown in the photograph. The hatch was cast with 17-4PH corrosion-resistant steel, and it underwent a heat treatment that is classified information.

CASTING PROBLEMS AND DEFECTS

Because metal flow is related to temperature, the pouring temperature for thin-wall castings is a critical factor. The fact that misruns were experienced in castings when all other variables were controlled attests to the importance of pouring temperatures with large, complex castings. Unfortunately, pouring temperatures for the castings were difficult to measure because of the nature of the pouring process and essential safety precautions. The metal for most successfully poured castings was tapped from an induction furnace at a minimum of 1,665° C. Temperature losses due to ladle transfer and endothermic destruction of the polystyrene were estimated at nearly 80° C. The liquidus of the metal was 1,560° C.

Hot-tear defects caused by mold constraint (*8*) and necessarily high pouring temperatures occurred around the top surface of the casting. The casting was unable to shrink evenly around the bonded-sand core, causing intolerable stresses around the top surface of the casting that resulted in the defect. Hot tears were largely eliminated by adding thickness to the webs at critical areas and by removing the extra material in finishing.

The addition of vacuum to molds was imperative to the complete filling of the castings shown in the figures. However, the vacuum increased metal velocity, and consequently, metal turbulence was greater. Pouring was accomplished accurately and rapidly to prevent a vortex from developing in the sprue and subsequent ingestion of air.

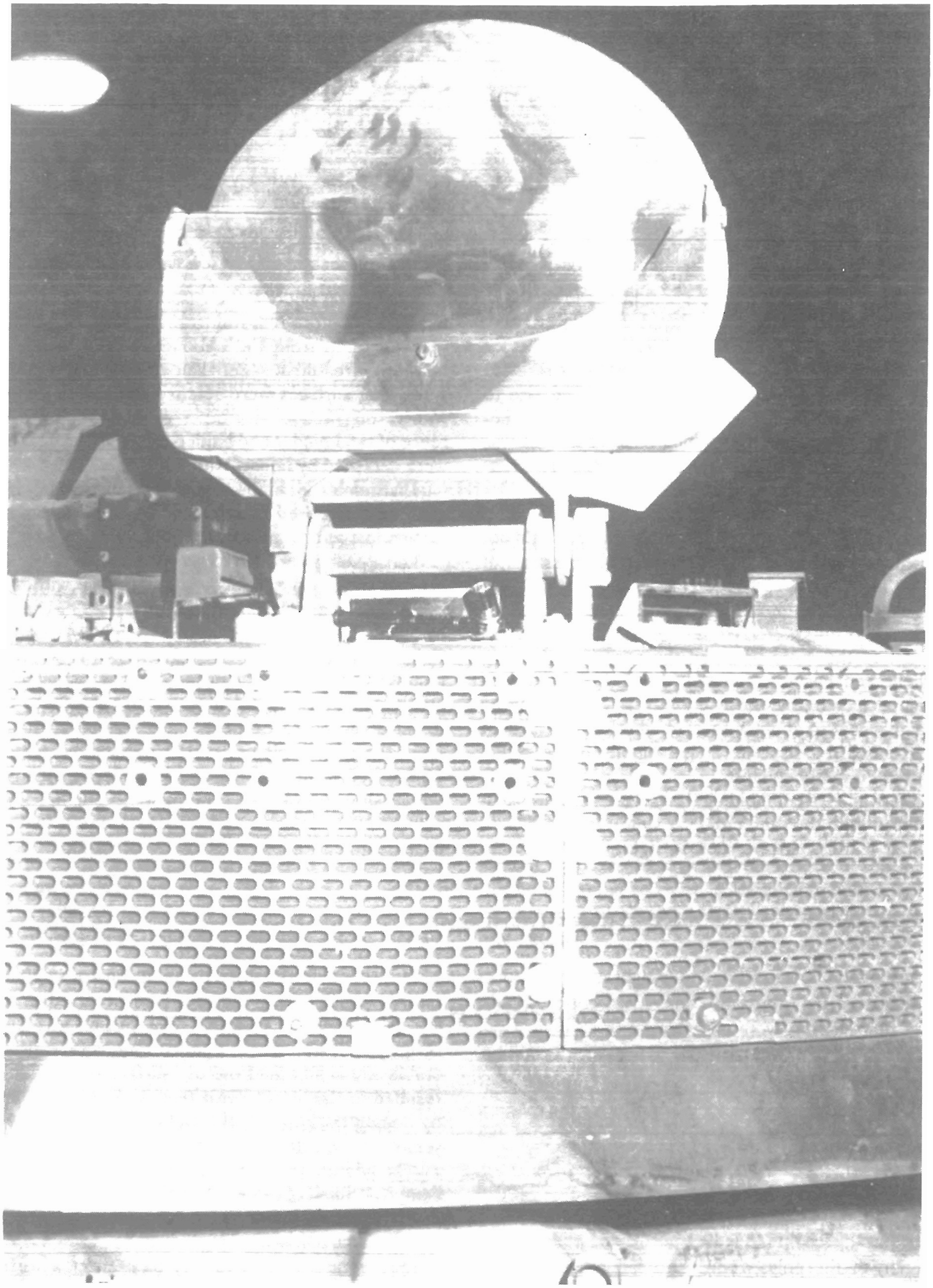

Figure 1.—Current Bradley Fighting Vehicle commander's hatch.

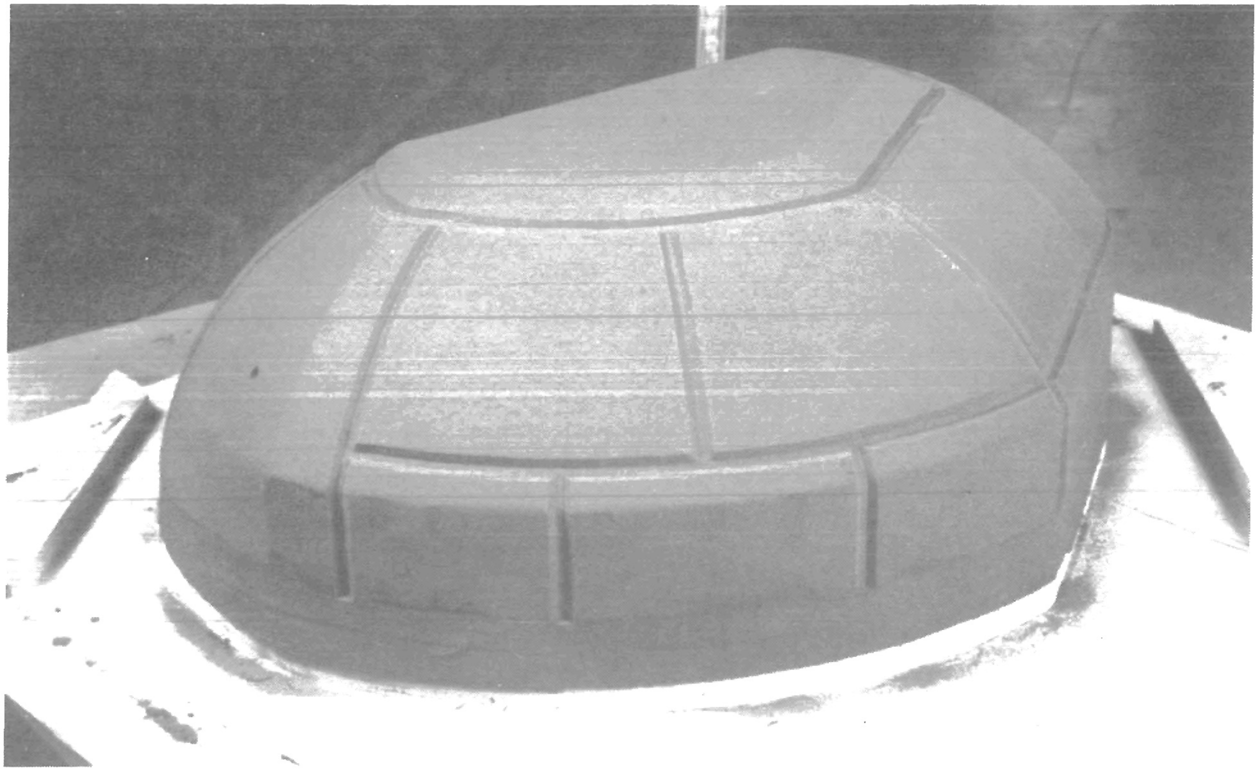

Figure 2.—Bonded-sand core showing reliefs for internal hatch ribs.

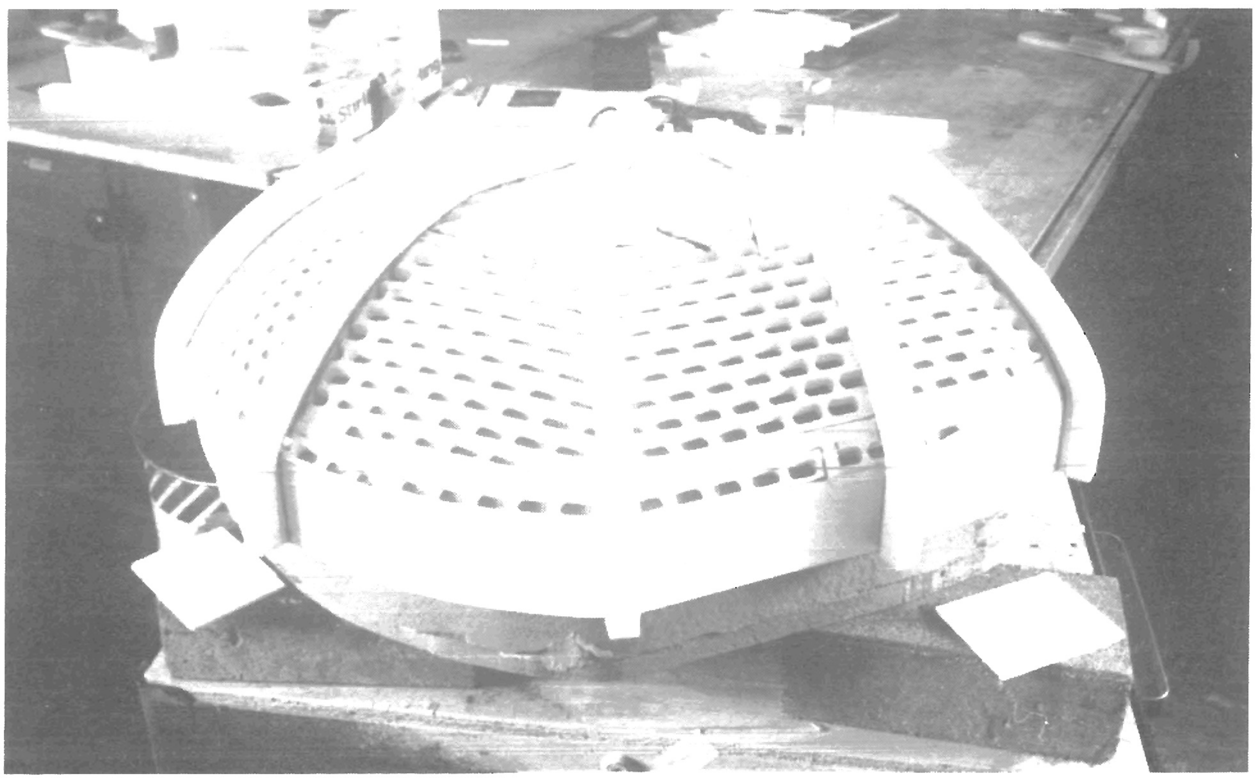

Figure 3.—Finished pattern, glued to bonded-sand core, with gating system and hot tear prevention bars attached.

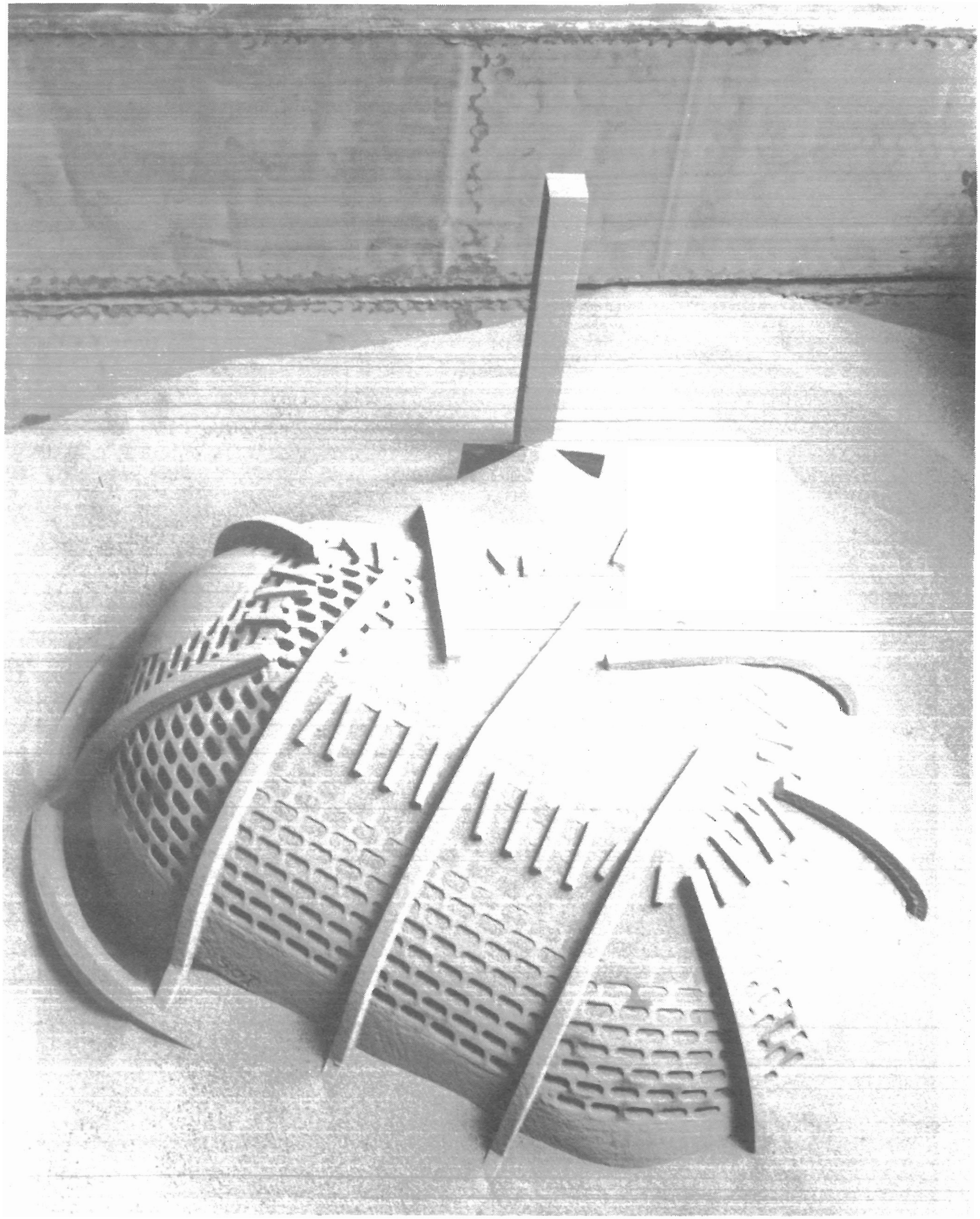

Figure 4.—Doubled-walled flask with coated pattern inserted.

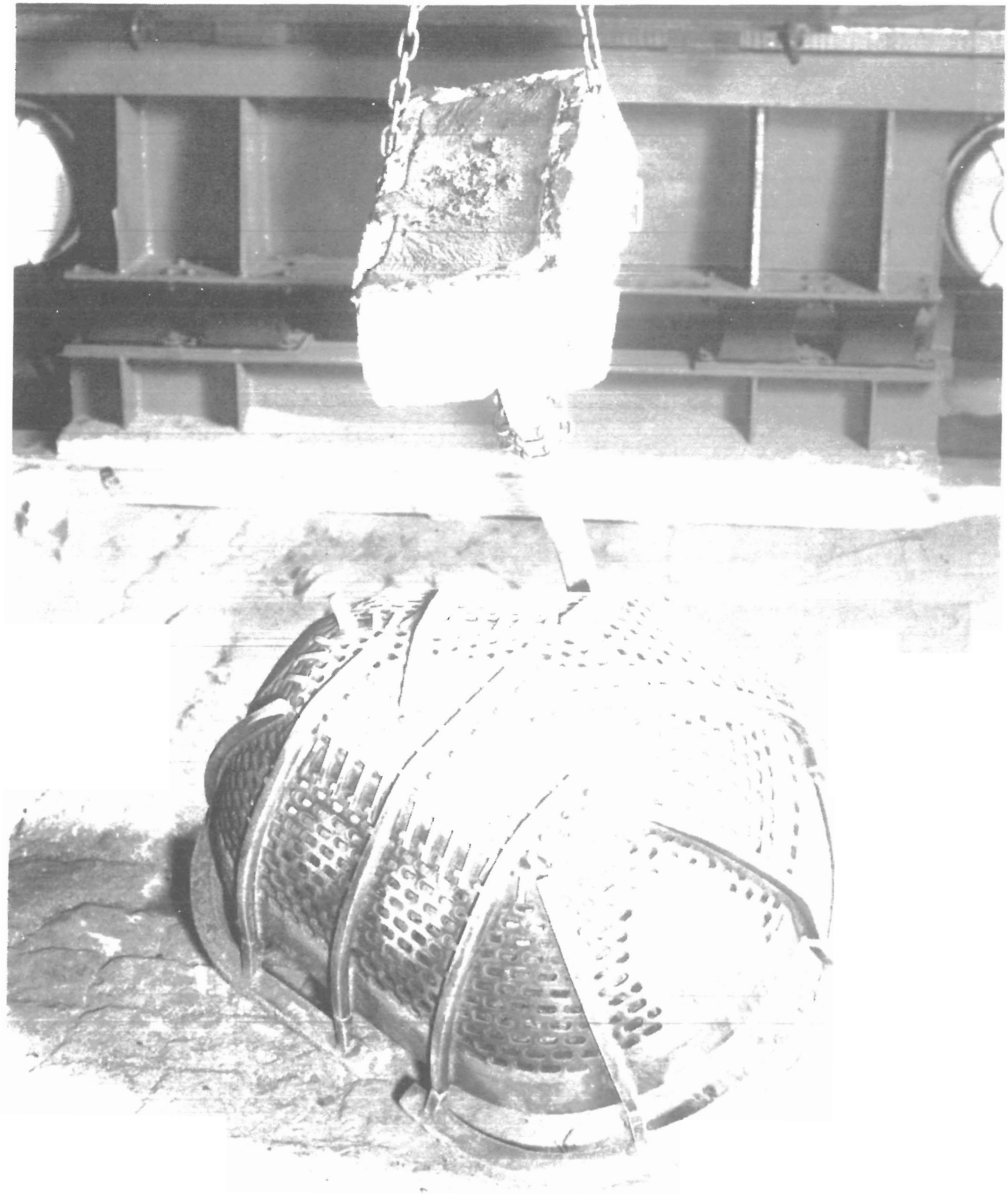

Figure 5.—Rough casting just removed from flask.

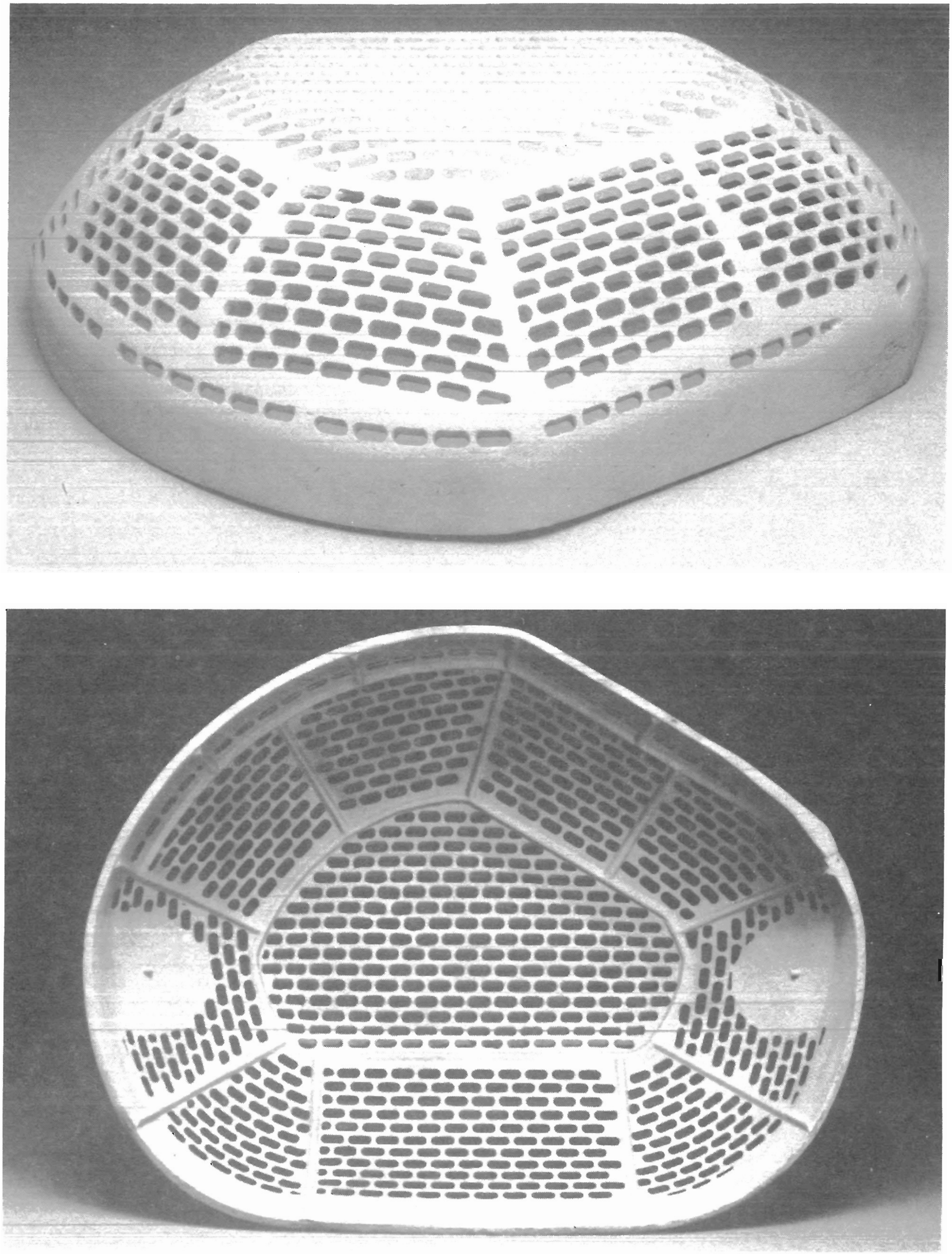

Figure 6.—Outer (top) and inner (bottom) surfaces of finished casting. Note cast-in ribs on inner surface of casting.

CONCLUSIONS

EPC is the only economical technology to make P-900 hatch covers. The EPC process can be used successfully to make complex steel castings if several modifications to conventional EPC technology are implemented. The modifications include (1) the application of vacuum to molds to assist metal flow, (2) continuous line-gate feeding systems to ensure hot metal delivery to extended thin wall sections, and (3) fixtures or cores to prevent distortion and maintain dimensional accuracy.

The use of vacuum has negative aspects that can be avoided if the minimum vacuum needed to achieve complete filling is determined. There are other hazards to expect. Too high a pouring temperature will promote hot tears, but too low a temperature will result in misruns.

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